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Chapter 17

Microbial Production of Xylitol

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Xylitol, a five-carbon polyalcohol, has attracted much attention because of its potential use as a natural food sweetener, as a dental caries reducer and as a sugar substitute in diets for diabetics. Currently, it is produced chemically by catalytic reduction of xylose. Various microorganisms can convert xylose to xylitol. The present review describes microbial production of xylitol from xylose and xylose rich hemicellulose fractions present in various lignocellulosic biomass.

Xylitol, a pentitol of xylose, has attracted much attention because of its potential use as a natural food sweetener, as a dental caries reducer and as a sugar substitute for treatment of diabetics (*1*). It is a normal intermediary product of carbohydrate metabolism in humans and animals. The human body produces 5-15 g of xylitol a day during a normal metabolism (*2*). Xylitol is widely distributed in the plant kingdom, especially, in certain fruits and vegetables (*1, 3, 4*). However, extracting it from these sources is impractical because it is generally present in small quantities. Xylitol is currently produced chemically by catalytic reduction of xylose present in hemicellulose (xylan) hydrolyzate in alkaline conditions (*5, 6*). The recovery of xylitol from the xylan fraction reaches about 50-60% (*4*). Drawbacks of the chemical process are the requirements of high pressure and temperature, use of an expensive catalyst and use of extensive separation and purification steps to remove the by-products mainly derived from hemicellulose hydrolyzate (*7*). The bulk of xylitol produced is consumed in various food products such as chewing gum, candy, soft drinks and ice cream (*2*).

Microorganisms for Xylitol Production

Xylitol is produced from D-xylose as a metabolic intermediate in many xylose utilizing microorganisms in two ways: D-xylose is directly converted to xylitol by NADPH-dependent aldehyde reductase (EC 1.1.1.21), or D-xylose is first isomerized to D-

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xylulose by D-xylose isomerase (EC 5.3.1.5) and then reduced to xylitol by NADH-dependent xylitol dehydrogenase (EC 1.1.1.9) (Fig. 1) (*8*). Many yeasts and mycelial fungi possess the enzyme xylose reductase which catalyzes the reduction of xylose to xylitol as a first step in xylose metabolism (*9*). Xylitol production is a relatively common feature among xylose-utilizing yeasts (*10*). In xylose fermenting yeasts, the initial reactions of xylose metabolism are the major limiting steps (*11*). This results in the accumulation of xylitol in culture medium, the degree varying with the culture conditions and the yeast strain used (*12*).

Onishi and Suzuki (*13*) examined 58 yeast strains belonging to the genera *Saccharomyces*, *Debaryomyces*, *Pichia*, *Hansenula*, *Candida*, *Torulopsis*, *Kloeckera*, *Trichosporon*, *Cryptococcus*, *Rhodotorula*, *Monilia* and *Torula* for polyalcohol production from pentose sugars such as D-xylose, L-arabinose and D-ribose. *Candida polymorpha* dissimilated aerobically these three pentoses and produced xylitol from xylose, L-arabitol from L-arabinose and ribitol from D-ribose at the yield of 30-40% of sugar consumed. Gong et al. (*10*) screened 20 strains of *Candida* belonging to 11 different species, 21 strains of *Saccharomyces* belonging to 8 species and 8 strains of *Schizosaccharomyces pombe* for their ability to convert xylose to xylitol. Significant quantities of xylitol were produced by all these yeast strains. Barbosa et al. (*14*) screened 44 yeasts from five genera (*Candida*, *Hansenula*, *Kluyveromyces*, *Pichia* and *Pachysolen*) for conversion of xylose to xylitol. All but two of the strains produced some xylitol with varying rates and yields. The best xylitol producers were localized largely in the species *C. guilliermondii* and *C. tropicalis*. Seven strains of *C. guilliermondii* from diverse isolation sources produced xylitol efficiently when grown in a simple medium containing 5.0% xylose within 24 h (*15*). However, xylitol essentially disappeared from all the cultures within 72 h. Sirisansaneeyakul et al. (*16*) selected *C. mogii* ATCC 18364 as an efficient xylitol producer (Yp/s = 0.62 g/g) from 11 strains of D-xylose utilizing yeasts. *Debaryomyces hansenii* was an efficient xylitol producer exhibiting a xylitol/ethanol ratio above 4 and a carbon conversion of 54% for xylitol (*17*). *C. entomaea* and *Pichia guilliermondii* produced 0.51 and 0.43 g xylitol/g xylose at pH 5.0 and pH 4.0, respectively and 34°C (*18*). *Ambrosiozyma monospora* NRRL Y-1484 produced about 22 g xylitol and 18 g ethanol from 100 g xylose per L when grown at 25°C under moderate aeration (*19*). A strain of *C. tropicalis* converted xylose to xylitol and did not produce ethanol (*20*). Significant quantity of xylitol was produced during ethanol fermentation by *Pachysolen tannophilus* (*21,22*) and *Kluyveromyces cellobiovorus* (*23*). Various thermo-tolerant yeasts have also been evaluated for the bioconversion of xylose into xylitol (*24*). Xylitol production ranged from 0.83 to 4.69 g from 10 g xylose.

A fungal strain of *Petromyces albertensis* produced xylitol when grown in a medium containing D-xylose (*25*). A large amount (36.8 g/L) of xylitol was obtained from a D-xylose (100 g/L) medium containing ammonium acetate and yeast extract at an initial pH of 7.0. The production of xylitol from xylose has been studied with bacteria such as *Enterobacter liquefaciens* (*26, 27*), *Corynebacterium* sp. (*28, 29*), and *Mycobacterium smegmatis* (*30*).

Onishi and Suzuki (*31*) screened 128 yeast strains for their ability to produce xylitol from glucose. They reported a sequential fermentation process of xylitol production from glucose (glucose⇨ D-arabitol⇨D-xylulose⇨xylitol) without isolation

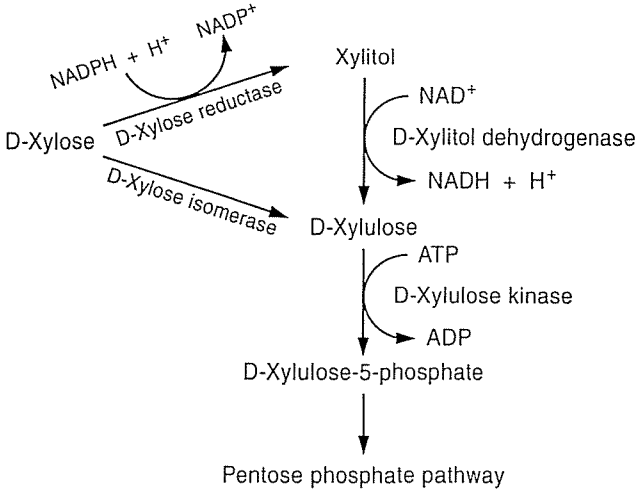

Figure 1. Pathway for xylose utilization by microorganisms.

and purification of the intermediates, and the yield of xylitol was 11% from glucose. *D. hansenii* converted glucose to D-arabitol, *Acetobacter suboxydans* oxidized D-arabitol almost quantitatively to D-xylulose and *C. guilliermondii* var. *soya* reduced D-xylulose to xylitol. Table I summarizes production of xylitol from xylose by some *Candida* species.

Table I. Production of xylitol from xylose by some *Candida* species

Yeast	Fermentation Time (h)	Xylose (g/L)	Xylitol (g/L)	Xylitol Yield (g/g)
Candida sp. B-22 (*32*)	167	249	210	0.84
C. boidinni 2201 (*33*)	120	100	40	0.40
C. guilliermondii FTI-20037 (*14*)	80	104	77.2	0.74
C. guilliermondii NRC 5578 (*34*)	406	300	221	0.75
Candida sp. L-102 (*35*)	65	114	100	0.88

Factors Affecting Xylitol Production

Medium Components. The conversion of xylose to xylitol by *C. guilliermondii* was affected by the nutrient source (*14*). Horitsu et al. (*36*) studied the influence of culture conditions on xylitol formation by *C. tropicalis* and optimized the volumetric xylitol production rate by the Box-Wilson method. In this respect, initial xylose concentration, yeast extract concentration and k_La were chosen as independent factors in 2^3-factorial design. Optimal product formation ($r_{xylitol}$ =2.67 g/L/h, $C_{xylitol}$ = 110 g/L) was obtained at 172 g/L xylose, 21 g/L yeast extract and a k_La of 451.5 L/h.

Xylose Concentration. Initial xylose concentration is an important factor to obtain high xylitol production. Meyrial et al. (*34*) reported that an increase in the initial xylose concentration from 10 g/L to 300 g/L led to activation of xylitol production by *C. guilliermondii*. The xylitol yield increased gradually with substrate, the highest xylitol yield (0.75 g/g xylose) was obtained at a substrate concentration of 300 g/L. However, the growth of the yeast was gradually inhibited by an increase in initial xylose concentration in the medium. Both the yield and specific rate of cells production declined when xylose concentration initially present in the culture increased. Chen and Gong (*32*) reported a xylitol yield of 84.5% of theoretical and a maximum production rate of 0.269 g/g/h from 249 g/L xylose by *Candida* sp. B-22. *C. tropicalis* HXP2 (*37*) and *C. boidinii* (*33*) produced the highest amounts of xylitol (144 g/L and 39 g/L, respectively) at respective values of substrate concentration of 200 g/L and 100 g/L. Dahiya (*25*) reported maximum xylitol production by *P. albertensis* was 36.8 g/L at the initial xylose concentration of 100 g/L. Xylitol production declined when the initial xylose concentration was increased to 150 g/L. This might be due to an osmotic effect on cells of *P. albertensis* or to substrate repression of xylose metabolizing enzymes.

When *C. mogii* was grown under oxygen-limited conditions in synthetic medium containing different concentrations of xylose (5-53 g/L), the xylitol formation rates showed a hyperbolic dependency on the initial substrate concentration (*16*).

Vandeska et al. (*38*) reported that an increase in initial xylose concentration induced xylitol production in *C. boidinii* but simultaneously acted as a growth inhibitory substrate leading to a long fermentation time. To overcome these problems, fed batch cultures were then used in which higher xylitol yields (0.57-0.68 g/g) and production rates (0.32-0.46 g/L/h) were obtained as compared with a batch process (*39*). A fed batch process with highest initial xylose concentration (100 g/L) and lowest level of aeration in the first phase, resulted in the highest yield of xylitol (75% of theoretical). A potentiometric biosensor for xylose to monitor fermentative conversion of xylose to xylitol was devised (*40*).

Presence of Other Sugars. Yahashi et al. (*41*) investigated the effect of glucose feeding on the production of xylitol from xylose by *C. tropicalis*. In the bench-scale fermenter (3 L scale) experiment, xylitol was produced at up to 104.5 g/L at 32 h cultivation and a yield of 0.82 (g/g xylose consumed) which is 1.3 times higher than that without glucose feeding. Meyrial et al. (*34*) evaluated the ability of *C. guilliermondii* to ferment non-xylose sugars such as glucose, mannose, galactose and L-arabinose commonly found in hemicellulose hydrolyzate. The strain did not convert glucose, mannose and galactose into their corresponding polyalcohol but only to ethanol and cell mass. Arabinose was converted to arabitol. Silva et al. (*42*) studied batch fermentation of xylose for xylitol production in stirred tank bioreactor. The efficiency of substrate conversion to xylitol was 66% in a medium containing xylose but decreased to 45% in a medium containing xylose and glucose. Vandeska et al. (*39*) investigated xylitol production by *C. boidinii* in fed batch fermentations with xylose (50, 100 g/L) and a mixture of glucose (25 g/L) and xylose (25 g/L). All fermentations were initially batch processes with high levels of aeration and rapid production of biomass. Faster growth occurred when a mixture of glucose and xylose was used instead of xylose. Glucose was assimilated first and maximal xylitol production was 39-41 g/L, compared with 46.5 and 59.3 g/L with xylose alone.

Nitrogen Sources and Organic Nutrients. Dahiya (*25*) studied the effect of 8 ammonium salts and 4 organic nitrogen sources on the production of xylitol from xylose by *P. albertensis*. Ammonium acetate was most effective for xylitol production. Yeast extract was the most suitable organic nutrient for enhancement of xylitol production. Lu et al. (*35*) investigated the effect of nitrogen sources [asparagine, casein hydrolyzate, glycine, Traders protein, yeast extract, urea, $NaNO_3$, NH_4NO_3, $(NH_4)_2SO_4$, NH_4Cl, $NH_4H_2PO_4$] on xylitol production from xylose in shake flasks by an efficient xylitol producing yeast, *Candida* sp. L-102. Different nitrogen sources influenced xylitol production rate, average specific productivity, and xylitol yield. Maximum xylitol production (100 g/L of xylitol from 114 g/L of xylose) was obtained with urea (3 g/L) as the nitrogen source. Silva et al. (*43*) evaluated the xylose conversion into xylitol by *C. guilliermondii* in semi-synthetic media supplemented with different nitrogen sources [urea, NH_4Cl, $(NH_4)_2SO_4$] in a ratio C/N equal 25.6. The type of nitrogen source did not influence this bioconversion and the xylitol yield was around 80%. On the other hand,

Barbosa et al. (*14*) reported that the use of urea led to higher xylitol productivity by *C. guilliermondii* than with ammonium sulfate, and supplementation of urea with casamino acids improved performance over urea alone only slightly. Yeast extract improved yields, but only slightly.

Magnesium and Biotin. Mahler and Guebel (*44*) studied the influence of Mg^{+2} concentration on growth, ethanol and xylitol production from xylose by *Pichia stipitis* NRRL Y-7124. Under constant oxygen uptake rate, biomass/xylose and biomass/Mg^{+2} yields increased with Mg^{+2} concentration with a maximum value at 4 mm. Ethanol was the main product formed. At low Mg^{+2} levels (1 mM), 49% of carbon flux to ethanol was redirected to xylitol production, and was correlated with intracellular accumulation of NADH.

Lee et al. (*45*) reported that the relative amount of ethanol and xylitol accumulated in xylose fed aerobic batch cultures of *P. tannophilus* and *C. guilliermondii* depended on the limitation by biotin. In high biotin containing media (2 µg/L) *P. tannophilus* favored ethanol production over that of xylitol while *C. guilliermondii* favored xylitol formation.

Methanol Supplementation. Dahiya (*25*) reported that addition of 1% methanol to the medium with 100 g/L xylose increased the xylitol production from 36.8 g/L to 39.8 g/L by *P. albertensis*. No significant difference in fungal biomass and xylulose accumulation was observed and only 0.015% methanol was consumed. This could be due to the oxidation of methanol to yield NADH which would enhance the reduction of xylose and xylulose to xylitol. Vongsuvanlert and Tani (*33*) reported about 18 and 26% increase in xylitol production from xylose in presence of 1 and 2% methanol, respectively by *C. boidinii*. This is also the case with the production of sorbitol from glucose and iditol from L-sorbose by *C. boidinii* (*46*).

Initial Cell Density. Cao et al. (*47*) investigated the effect of cell density on the production of xylitol from xylose by *Candida* sp. B-22. The rate of xylitol production from xylose increased with increasing yeast cell density. At high initial yeast cell concentration of 26 mg/ml, 210 g/L of xylitol was produced from 260 g/L of xylose after 96 h of incubation with a yield of 81% of the theoretical value. Vandeska et al. (*38*) reported that high initial cell densities improved xylitol yields and specific production rates of xylitol by *C. boidinii*. The susceptibility of wood hydrolyzate to fermentation by *D. hansenii* NRRL Y-7426 was strongly dependent on the initial cell concentration (*48*).

Oxygen Supply. A variety of yeasts such as *Candida*, *Hanensula*, *Klyveryomyces*, and *Pichia* require oxygen for sugar uptake (*49*) and availability of oxygen has significant influence on xylose fermentation by these yeasts (*10*). However, oxygen limitation is the main factor stimulating the formation of xylitol (*50*). Roseiro et al (*17*) reported that xylitol production by *D. hansenii* required semianaerobic conditions. The presence of oxygen enhanced NADH oxidation and a high NAD+/NADH ratio led to xylitol oxidation to xylulose; therefore, less xylitol was accumulated. Thus the yield of xylitol depended strongly on the oxygen transfer rate (*51*). Horitsu et al. (*36*) reported that higher level of dissolved oxygen is required only at the earlier phase of cultivation and

afterwards it should be decreased to the lower level of respiration by the yeast. Barbosa et al. (*14*) reported that increasing oxygen limitation led to increased xylitol productivity and decreased ethanol production with *C. guilliermondii*. Nolleau et al. (*11*) evaluated the ability of *C. guilliermondii* and *C. parapsilosis* to ferment xylose to xylitol under different oxygen transfer rates. In *C. guilliermondii*, a maximal xylitol yield of 0.66 g/g was obtained when oxygen transfer rate was 2.2 mmol/l· h. Optimal conditions to produce xylitol by *C. parapsilosis* (0.75 g/g) arose from cultures at pH 4.75 with 0.4 mmols of oxygen/l· h. The oxygen is not only an important factor to optimize the xylitol production but it is also an essential component for xylose assimilation. When aerobic batch cultures of *C. guilliermondii* and *C. parapsilosis* provided with xylose, were shifted to anaerobic conditions, the xylose concentration remained at a constant level and all metabolic activities stopped immediately. *C. mogii* produced xylitol from xylose under aerobic and oxygen-limiting conditions, but not without oxygen (*16*). Xylose conversion into xylitol by *C. guilliermondii* FTI 20037 was investigated in a stirred tank bioreactor at different stirring rates (*42*). Maximal xylitol production (22.2 g/L) was obtained at 30°C, with an aeration rate of 0.46 vvm using a stirring rate of 300 per min ($k_La = 10.6\ h^{-1}$). An increase of k_La caused an increase in the consumption of xylose in detriment to xylitol formation. Winkelhausen et al. (*52*) investigated xylitol formation by *C. boidinni* in oxygen limited chemostat culture. The production of xylitol by the yeast occurred under conditions of an oxygen limitation at specific oxygen uptake rates lower than 0.91 mmol/gh. The efffect of aeration on xylitol production from xylose by some yeasts is summarized in Table II.

Xylitol Production by Recombinant *Saccharomyces cerevisiae*

The yeast *Saccharomyces cerevisiae* is not able to use xylose or xylitol as a carbon source for growth or fermentation (*54*). Hallborn et al. (*55*) obtained efficient conversion of xylose to xylitol by transforming *S. cerevisiae* with the gene encoding the xylose reductase (XR) gene (*XYL1*) of *Pichia stipitis*. Due to lack of xylitol dehydrogenase (XDH), the recombinant *S. cerevisiae* needs a co-carbon substrate to regenerate the cofactors and to gain maintenance energy. Hallborn et al. (*56*) studied the influence of cosubstrate and aeration on xylitol formation by the recombinant *S. cerevisiae*. With glucose and ethanol, the conversion yields were close to 1 g xylitol/ g consumed xylose. Decreased aeration increased the xylitol yield based on consumed cosubstrate, while the rate of xylitol formation decreased. Xylitol yields close to 100% could be obtained from a medium with a total xylose concentration corresponding to that of an industrial hemicellulose hydrolyzate by fed-batch cultivation of recombinant *XYL1* expressing *S. cerevisiae* using ethanol as co-substrate (*57*). Recently, Roca et al. (*58*) investigated the effect of hydraulic residence time (1.3-11.3 h), substrate/cosubstrate ratio (0.5 and 1), recycling ratio (0.5 and 10), and aeration (anaerobic and oxygen limited conditions) on xylitol production by immobilized recombinant *S. cerevisiae* in a continuous packed-bed bioreactor.

Enzymatic Production of Xylitol from Xylose

The enzymatic production of xylitol from xylose using xylose reductase of *C. pelliculosa*

Table II. Effect of aeration on xylitol production from xylose by some yeasts

Yeast	Xylose (g/L)	Aeration	Xylitol yield (g/g)
Candida tropicalis (*36*)	100	100 ml/min	0.49
	100	400 ml/min	0.57
	100	500 ml/min	0.45
	100	700 ml/min	0.38
C. guilliermondii (*51*)	100	Microaerobiosis	0.50
	100	Semiaerobiosis	0.49
	100	Aerobiosis	0.56
C. parapsilosis (*51*)	100	Microaerobiosis	0.74
	100	Semiaerobiosis	0.61
	100	Aerobiosis	0.50
C. parapsilosis (*53*)	10	0.15 vvm	0.31
(continuous culture)	10	0.30 vvm	0.27
	10	0.60 vvm	0.08
	10	1.00 vvm	0.04
	10	1.50 vvm	0.02
	10	2.00 vvm	0.04

coupling with the oxidoreductase system of *Methanobacterium* sp. capable of recycling NADP (H) has been demonstrated by Kitpreechavanich et al. (*59*). A sulfonated polysulfone membrane reactor for *in situ* regeneration and retention of coenzymes NADP (H) using the xylose reductase of *C. pelliculosa* coupled with oxidoreductase system of *Methanobacterium* sp. in the reduction of xylose to xylitol with hydrogen gas was also used (*60*). The membrane rejected the permeation of NADP (H) (92 and 97%) F_{420} (97%) and the required enzymes (100%) almost completely, but did not reject for the permeation of xylitol. Nishio et al. (*61*) reported the enzymatic conversion of xylose into xylitol by the immobilized cells of *C. pelliculosa* (NADP+ dependent xylose reductase) coupled with the immobilized cells of *Methanobacterium* sp. HU (hydrogenase and F_{420}-NADP+ oxidoreductase) using hydrogen as an electron donor. The continuous production of xylitol in a column reactor packed with the co-immobilized cells could operate stably for 2 weeks. Xylitol was produced from xylose using commercial immobilized xylose isomerase from *Bacillus coagulans* and immobilized cells of *M. smegmatis* (*30*). From 10 g xylose, 4 g of xylitol was produced and 5 g xylose remained in the reaction mixture; no xylulose was detected. The washed cells of *M. smegmatis* converted xylulose to xylitol under aerobic and anaerobic conditions. The washed cells of a gluconate-utilizing *Corynebacterium* strain grown in a gluconate-xylose medium produced xylitol from xylose in the presence of gluconate (*29*). Xylose was reduced to xylitol by coupling the xylose reductase activity to the 6-phosphogluconate dehydrogenase activity with NADP as a cofactor using cell-free extract and the fractionated enzymes of *Corynebacterium* strain.

Production of Xylitol from Hemicellulose Hydrolyzate

Hemicellulose is one major component of plant cell wall materials, comprising up to 40% of agricultural residues and hardwood. It can be hydrolyzed by using dilute acids under mild hydrolysis conditions to yield a mixture of sugars (glucose, xylose, L-arabinose, mannose) of which xylose is the major component. These xylose containing hemicellulose hydrolyzates can serve as potential substrates for xylitol production. However, during acid hydrolysis, many potentially toxic compounds such as acetic acid, furfural, phenolic compounds, or lignin-degradation products are formed which inhibit growth of yeast.

Chen and Gong (*32*) studied the fermentation of sugarcane bagasse hemicellulose hydrolyzate to xylitol by a hydrolyzate-acclimatized yeast strain *Candida* sp. B-22. With this strain, a final xylitol concentration of 94.74 g/L was obtained from 105.35 g/L xylose in hemicellulose hydrolyzate after 96 h of incubation. *C. guilliermondii* FTI 20037 was able to ferment a sugar cane bagasse hydrolyzate producing 18.4 g/L xylitol from 29.5 g/L of xylose, at a production rate of 0.38 g/L/h (*62*). This lower value, compared to that (0.66 g/L/h) of the synthetic medium, may be attributed to the various toxic substances that interfere with microbial metabolism (e.g., acetic acid). Dominguez et al. (*63*) studied different treatments (neutralization, activated charcoal and neutralization, cation-exchange resins and neutralization) of sugar cane bagasse hemicellulose hydrolyzate to overcome the inhibitory effect on xylitol production by *Candida* sp. 11-2. The highest xylitol productivity (0.205 g/L/h), corresponding to 10.54 g/L, was obtained from hydrolyzates treated with activated charcoal (initial xylose, 42.96 g/L). To obtain higher xylitol productivity, treated hydrolyzates were concentrated by vacuum evaporation in rotavator to provide higher initial xylose concentration. The rate of xylitol production increased with increasing initial xylose concentration from 30 to 50 g/L, reaching a maximum of 28.9 g/L after 48 h fermentation. The decrease in xylitol production was dramatic with further increases in the initial xylose concentration. Parajo et al. (*48*) later reported a xylitol production of 39-41 g/L from concentrated *Eucalyptus globulus* wood acid hydrolyzate containing 58-78 g xylose/L by *Debaryomyces hansenii* NRRL Y-7426 using an initial cell concentration of 50-80 g/L.

Roberto et al. (*64, 65*) tested hydrolyzed hemicellulosic fractions of sugar cane bagasse and rice straw for xylitol production in batch fermentation by *C. guilliermondii* under semi-aerobic condition and compared these with synthetic medium containing xylose. For all media tested, simultaneous utilization of hemicellulosic sugars (glucose and xylose) was observed and the highest substrate uptake rate was attained in sugar cane bagasse medium. Increased xylitol concentration (40 g/L) was achieved in synthetic and rice straw media, although the highest xylitol production rate was obtained in sugar cane bagasse hydrolyzate. They concluded that both hydrolyzates can be converted into xylitol with satisfactory yields and productivities. Roberto et al (*66, 67*) evaluated xylitol production by *C. guilliermondii* in a rice straw hemicellulose hydrolyzate under different conditions of initial pH, nitrogen sources and inoculum level. The xylitol yields were 0.68 g/g for the medium containing ammonium sulfate at pH 5.3 and 0.66 g/g with urea at pH 4.5. Under appropriate inoculum conditions rice straw hemicellulose hydrolyzate was converted into xylitol by the yeast with efficiency values as high as 77% of the theoretical maximum. The production of xylitol from various hemicellulosic hydrolyzates is presented in Table III.

Gurgel et al. (*68*) studied xylitol recovery from fermented sugarcane bagasse hydrolyzate. The best clarifying treatment was found by adding 25 g activated carbon to 100 ml fermented broth at 80°C for 1 h at pH 6.0. The clarified medium was treated with ion-exchange resins after which xylitol crystallization was attempted. The ion exchange resins were not efficient but the crystallization technique showed good performance, although the crystals were involved in a viscous, colored solution.

Table III. Fermentative production of xylitol from hemicellulose hydrolyzates

Yeast	Substrate source	Fermentation Time (h)	Xylose (g/L)	Xylitol (g/L)	Xylitol (g/g)
Candida sp. B-22 (*32*)	Sugar cane	96	105.4	96.8	0.89
Candida sp. 11-2(*63*)	Sugar cane	48	42.96	10.54	-
C. guilliermondii FTI 20037 (*62*)	Sugar cane	-	29.50	18.40	-
C. guilliermondii FTI 20037 (*66*)	Rice straw	72	64	37.6	0.62
Debaryomyces hansenii NRRL Y-7426(*48*)	Wood	78	78	41	0.73

Concluding Remarks

The demand for xylitol in the food and pharmaceutical industries as an alternative sweetener has created a strong market for the development of low cost xylitol production process. Various xylose rich hemicellulosic materials can serve as abundant and cheap feedstocks for production of xylitol by fermentation. The cellulosic fraction can be converted to glucose, which is then fermented to fuel ethanol by *S. cerevisiae*. Much research needs to be done to select a suitable microorganism that can convert xylose into xylitol efficiently in presence of other hemicellulosic sugars and to understand the regulation and optimization of xylitol production by fermentation.

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